The Calculation and Analysis of Water Resource Carrying Capacity in Chongqing, China

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***Abstract*-The fast urbanization in Chongqing has had a great impact on the environment and resources. The water resource has been recognized as one of the key elements to the sustainable development of this region. This paper presents a method of predicting the regional Water Resource Carrying Capacity (WRCC) using the supply-demand balance model. The method predicts that the WRCC of Chongqing is from 110 million persons to 160 million persons in 2020 and it will not become the bottleneck of the social and economic development of Chongqing in the coming period of time. However the climate change and its impact on the regional ecology will have an effect on it. The results show that the climate is the most important element of the WRCC of Chongqing and the protection of the ecological environment in the upstream area is also very important. This paper has proposed tangible advice on the sustainable social and economic development in context of water resource.**

Keywords-Sustainable Development; Water Resource Carrying Capacity (WRCC); Urbanization; Chongqing

I. INTRODUCTION

Sustainable utilization of water resources is vital to human existence and socio-economic sustainable development. With the rapid population growth and socio-economic development, the demand for water is increasing and water resources are under mounting pressure. Water resource has been recognized as one of the key elements to the sustainable development in a region. So study on the amount of available water resources is very important.

Water Resource Carrying Capacity (WRCC) has been recognized as a key indicator for study on the amount of regional available water resources. It still didn't get a united definition currently [1][2], but many foreign researchers, such as Rijsberman M.A.[3], Joardar S.D.[4]and Harris J.M.[5], already use the indicator to measure the amount of available water resources because of its importance. In China the earliest research of WRCC was in Xinjiang in 1985[6], later many scholars, such as Shi Y-F[7], Xv Y-P[8], Xv Z-M[9], Jiang X-H[10], Zhang Y-G[11], adopted various methods to calculate the WRCC in various areas.

The WRCC is complex and it shows the following properties:

- Time effectiveness. The value of WRCC will change with the passage of time, so the calculation of WRCC needs a limit of time and the time is best from 10 to 20 years in the near future.
- Item constraints. The calculation of WRCC needs some constraint conditions, and the value of WRCC varies along with changes of constraint conditions. In all constraint conditions, social development level, technical and economic condition and the virtuous circle of ecosystem usually are the key element.
- Practicability. The research of WRCC needs to guild significance for regional socio-economic sustainable development, and the conclusion of research should be simple and practical. The prediction of regional socio-economic development scale is inclined to select macroscopic indicator, so the calculation of regional population size is more important for WRCC.

According to the analysis of above properties and research of Cao J-T [2] and Jiang W-C [12], a supply-demand balance model of regional water resources has been established in this paper. By using the model to make calculation of WRCC in Chongqing in 2020, the result of this study will provide reference data for various socio-economic and medium-long term plans in Chongqing.

II. METHODS AND STUDY AREA

A. Calculation Methods

The WRCC which is limited by many elements, such as population, economy and environment, is a reflection of regional socio-economic development scale. It can be computed when the water resource is in a supply-demand balance.

The computational model can be defined as:

$$W_C = \max f\{C_1, C_2, C_3, \ldots, C_j\} \quad (1)$$

$$W_{demand} = W_{supply} \quad (2)$$

where W_C is a regional WRCC, f is a comprehensive benefit function, C_j are various constraint indices, such as population, economic and environmental indicator. W_{demand} is the demand total amount of water resources for regional socio-economic development, W_{supply} is the regional available total amount of water resources.

The demand total amount of water resources for regional socio-economic development (W_{demand}) includes domestic water consumption, productive water consumption and ecological water requirement. The productive water consumption mainly includes industrial water consumption and agricultural water consumption, the water consumption of tertiary industry is considered as part of industrial water consumption.

The form of demand total amount of water resources (W_{demand}) can be presented as:

$$W_{demand} = W_D + W_I + W_A + W_E \quad (3)$$

where W_D is domestic water consumption, W_I is industrial water consumption, W_A is agricultural water consumption, W_E

is ecological water requirement. The calculation forms of W_D, W_I and W_A can be presented as:

$$W_D = R_{DU} \times P_U + R_{DA} \times P_A \quad (4)$$

$$W_I = U_I / P_I \quad (5)$$

$$W_A = R_{AI} \times A_I \quad (6)$$

where R_{DU} and R_{DA} are urban domestic water consumption standard and rural domestic water consumption standard, its unit is L/（p•d）. P_U and P_A are urban population quantity and rural population quantity. U_I is the gross industrial output value, P_I is the average industrial output value of per unit water, and the unit of P_I is ten thousand Yuan/m^3. R_{AI} is the agricultural water consumption standard of effective irrigation area, its unit is m^3/hm^2. A_I is the agricultural effective irrigation area.

The ecological water requirement means the minimal water demand for supporting the integrality and the virtuous circle of ecological system in the region, which can be divided into the ecological water requirement inside river channels and the ecological water requirement outside river. The functions of ecological water requirement inside river channels are mainly to prevent the dry river, to maintain the habitat of aquatic organisms, to keep riverbed stability and water self-purification ability. The ecological water requirement inside river channels accounts for 50~60% of annual average run-off volume in general [13]. The ecological water requirement outside river mainly includes ecological water requirement of vegetation, lake and wetland, etc, which is relatively constant and depends mainly on regional ecological environment status and ecosystem type. In urban area, the ecological water requirement outside river also includes urban municipal water consumption [14].

The calculation forms of regional socio-economic development scale can be defined as:

$$U = U_I + U_A = U_I + P_{RA} \times A_R \quad (7)$$

$$U_P = U / P = (U_I + U_A) / P = (U_I + P_{RA} \times A_R) / P \quad (8)$$

$$P = P_U + P_A = P \times r + P \times (1 - r) \quad (9)$$

where U is industrial and agricultural gross output value, U_P is per-capita industrial and agricultural output value. For making the equations be easy to calculate, GDP and per-capita GDP can be instead of U and U_p. U_A is agricultural gross output value, P_{RA} is unit area agricultural average output value, A_R is area of agricultural production, P is population quantity, and r is urbanization rate.

The regional available total amount of water resources ($W_{sup\ ply}$) includes regional internal total water resources quantity and regional external water flow. The regional internal total water resources quantity includes surface and subsurface water yield from local precipitation, the surface and subsurface water yield is called too surface water resources amount and ground water resources amount.

The regional external water flow means available input amount of water resources from external region.

The calculation forms of regional available total amount of water resources ($W_{sup\ ply}$) can be defined as:

$$W_{sup\ ply} = W_R + W_{Ex} \quad (10)$$

where W_R is regional internal total water resources quantity, W_{Ex} is regional external water flow.

On condition that dimension is neglected, with solving simultaneous equations (2)~(10), the WRCC can be calculated and be defined as:

$$P = \frac{W_R + W_{Ex} - W_E + P_{RA}A_R/P_I - R_{AI}A_I}{R_{DU} \times r + R_{DA} \times (1-r) + U_P/P_I} \quad (11)$$

where P is the regional Water Resource Carrying Capacity (WRCC). If the regional available total amount of water resources ($W_{sup\ ply}$), urbanization rate and other related technical and economic indicator can be predicted in a region, the regional population size (WRCC) can be calculated.

B. Study Area

Chongqing is located at 28°10'～32°13' north latitude and 105°11' ～ 110°11' east longitude(Fig.1). It is a large commercial and industrial center, and has convenient communications. In 1997, it was granted as the fourth municipality of China. Covering an area of 0.0824 million square kilometers, the municipality is 470 kilometers wide from east to west and 450 kilometers long from north to south. There were a total of 19 districts and 21 counties in Chongqing in 2007. Chongqing's eastern part is lower than the western part, with lots of hills in the northwest and in the middle areas, Daba Mountain, and Wuling Mountain stretch to the southeast. Chongqing has a subtropical humid monsoon climate with four distinct seasons. The summer of Chongqing is hot and the winter is warm, with a long frost-free period. In 2007 annual average temperature of this region was 19.0℃ and its annual precipitation was 1439.2mm [15].

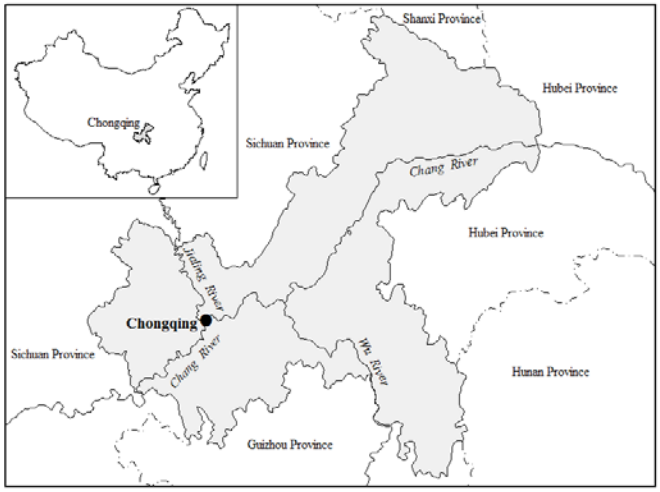

Fig 1. The location of Chongqing municipality.

Chongqing's GDP is 4122.51 hundred million Yuan in 2007, in which the primary industry is 482.39 hundred million Yuan (12.2%), the secondary industry is 1892.10 hundred million Yuan (43.0%), and the tertiary industry is 1748.02 hundred million Yuan (44.8%). Chongqing's per-capita GDP is 14660 Yuan and its total resident population is 28.16 million in 2007, there is a high speed of urbanization in Chongqing, of which the growth rate of urban population has increased to 48.3% in 2007 from 31.3% in 1999[15].

III. RESULTS AND DISCUSSION

According to the conditions of Chongqing's middle and long-term social and economic development planning compilation and the time effectiveness of WRCC, the calculation time of WRCC was determined as 2020 in this paper.

A. Demand Total Amount of Water Resources (W_{demand})

1) Domestic Water Consumptiont:

The domestic water consumption includes urban domestic water consumption and rural domestic water consumption.

The urban domestic water consumption mainly includes resident living water, resident municipal water, environmental sanitation and Greening water, in which the resident living water occupy 50%~70% in general. The rural domestic water consumption mainly includes resident living water, environmental sanitation, and drinking water of livestock. The urban and rural per-capita domestic water consumption is respectively 212 L/d and 68 L/d in China at present [13], Chongqing's per-capita domestic water consumption is about 112 L/d and 68 L/d at present [16].

According to the regulations Ministry of Housing and Urban-Rural Development of the People's Republic of China and Ministry of Health of the People's Republic of China, the urban per-capita resident living water consumption standard is 100~140 L/d in Chongqing[17], the rural per-capita resident living water consumption standard is 50~90 L/d in Chongqing[18].

Considering that Chongqing's social economic will reach a higher level in 2020, the urban per-capita domestic water consumption standard was determined as 212 L/d, and the rural per-capita domestic water consumption standard was determined as 105 L/d in this paper.

2) Productive Water Consumption

The average industrial output value of per-unit water was about 50 Yuan/m^3, and the agricultural water consumption standard of effective irrigation area was 30m^3/hm^2 in recent years in China [13]. The average industrial output value of per-unit water and the agricultural water consumption has an increasing trend in Chongqing in recent years [15]. In Chongqing, the ten thousand Yuan industrial water consumption is 135 m^3, and the agricultural water consumption of per-unit area is about 3255 m^3/hm^2 in 2006[16].

According to analysis of above indicator and research of Wang H [13], Chongqing's ten thousand Yuan industrial output value standard was determined as 40 m^3, and Chongqing's annual agricultural water consumption standard was determined as 6675 m^3/hm^2 in 2020 in this paper.

According to the scheme of Chongqing's Eleventh Five-Year Plan for National Economic and Social Development, Chongqing's per-capita GDP was determined as 45000 Yuan in 2020 in this paper.

The agricultural output value accounts for GDP proportion is 12.2% in 2007 and has a decrease trend in recent years in Chongqing [15]. The agricultural output value accounts for GDP proportion was determined as 5% in 2020 in this paper, and the agricultural gross output value was determined as 600 billion Yuan, agricultural average output value per hectare was determined as 4.5 ten thousand Yuan, the agricultural effective irrigation area was determined as 80 ten thousand hectares.

According to the Urban-Rural Master Planning of Chongqing (2007-2020), Chongqing's urbanization rate was determined as 70% in 2020 in this paper.

3) Ecological Water Requirement:

According to analysis of above paragraphs，the ecological water requirement inside river channels was determined as 60% of annual average run-off volume in this paper.

Landform of Chongqing is paralleled ridge-valley of east Sichuan, and there is higher vegetation coverage in Chongqing. Combining with research of Lin C [19], the ecological water requirement outside river of Chongqing was predicted as 4.35 billion m^3 in 2020 in this paper.

B. Available Total Amount of Water Resources (W_{supply})

1) Total Amount of Water Resources:

In general, total amount of regional water resources is the average value for many years. According to analysis of Chongqing Municipal Bureau of Water Resources，the total amount of regional water resources is 567.72524 billion m^3, and thel annual average runoff volume is also 567.72524 billion m^3[16].

2) Regional External Water Flow:

The regional external water flow includes artificial water diversion and available amount of transit water. There is no relevant planning of artificial water diversion from external region in Chongqing, so the regional external water flow of Chongqing is an available amount of transit water.

With 207 river basin area more than 100 km^2 and 40 river basin areas more than 1000 km^2, Chongqing's river system is centripetal, asymmetrical，and braided. Yangtze River, Jialing River, and Wu River are the largest river in Chongqing. The transit water amount is enormous in Chongqing, its average value for many years is 3981.32 billion m^3 [20].

The available transit water mainly depends on the reasonable distribution of transit water in its basin. The water distribution method of river basin is not generally accepted at home and abroad recently, but regional fairness principle is fundamental for reasonable distribution of transit water in its basin [21]. In a sense, the regional fairness principle needs to reflect difference between upstream and downstream of a river basin in land resources and social economic development level and needs to keep sustainable development of the whole basin. So the land area proportion and population quantity reflecting social economic development level are considered to be the basis for distribution of transit water in its basin in this paper.

Chongqing's land area accounts for 4.58% of total area of Yangtze River basin, and its population accounts about for 8% of total population of Yangtze River basin [15]. So the 4.58% and 8% are considered to be the lower limit value and the upper limit value of available transit water amount proportion of Chongqing in this paper. Hereby, available transit water amount of Chongqing can be calculated. Its value is 182.344~318.5056 billion m^3.

According to equations (10), the available total amount of water resources can be calculated. Its value is 334.4721~470.6332 billion m^3.

3) Water Resource Carrying Capacity(WRCC):

According to equations (11) and determined data from paragraphs above, the WRCC can be calculated in Chongqing with its value for 110~160 million people in 2020. Chongqing's population is 28.16 million in 2007[15], so water resource will not become a main limiting element of Chongqing's social and economic development in the near future. But water resources utilization of Chongqing needs to pay attention to the following respects:

- Chongqing's available total amount of water resources has a bigger change. The available amount of water resources from Chongqing area is 380.3191 billion m^3 in dry year [16]. It is only 66.99% of average value for many years, and the lowest value of available transit water in Chongqing is 182.3445 billion m^3, with the highest value reached up to 318.5056 billion m3. The climate change is a key factor to Chongqing's WRCC, and Chongqing's available total amount of water resources has a decrease trend in recent years.
- The calculation results show that water resource is not a main limiting element of Chongqing's social economic development. But the spatial distribution of water resource and socio-economic development of each district are imbalanced in Chongqing, so the water resource probably has a stronger restriction effect to the development of some districts of Chongqing.

IV. CONCLUSIONS

WRCC is a key element for sustainable utilization of regional water resources. According to the calculation results of this paper, for reducing the negtive effects of water resource to Chongqing's socio-economic sustainable development, the Chongqing municipality government should enhance the following respects:

- To establish the water distribution agreement of relative river basin of Chongqing for ensuring calculation accuracy of WRCC. It's a difficulty to calculate the available transit water amount in WRCC. The reasonable distribution of transit water is a key element for calculating available transit water amount.
- To ensure realization of various technical and economic indexes. Various technical and economic indicators are constraint conditions to calculate regional WRCC. The calculation of WRCC is not only to calculate the regional population scale, the calculation, and realization of various technical and economic indicators are important too. Calculation result of WRCC may be a bigger error if some technical and economic indicators can not be achieved.
- Establish water-saving society is significant to improve Chongqing's WRCC. According to the supply and demand balance model of regional water resources in this paper, when the regional available total amount of water resources keeps invariant, reducing the demand total amount of water resources can improve the regional WRCC. It's very important to improve water-use efficiency, reduce water pollution, ensure ecological water use, and realize regional sustainable development to establish water-saving society.

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